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Assessment Methodology for Northwest Atlantic Shrimp Stocks

by

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Abstract

Fisheries for the northern shrimp (Pandalus borealis) in the Canadian Northwest Atlantic are relatively new. Assessment of the stocks has been based on experience from more well-established fisheries which utilize various exploitation rates applied to estimates of stock size obtained from areal expansion methods. Improvements in currently used methodology can be made through a more complete understanding of shrimp biology, addressing problems such as growth, mortality, recruitment, predator-prey relationships and environmental factors.

There are few alternative approaches to the assessment of shrimp stocks. Traditional analytical fisheries models may provide some useful information but require refinement in the precision of biological parameters. Recent developments in the analyses of length frequencies may be applicable to shrimp data.

Research efforts should be directed primarily at the improvement of existing methodology and development of new methodology rather than annual assessment of numerous stocks.

Résumé

La pêche des crevettes nordiques (Pandalus borealis) est de date relativement récente dans le nord-ouest de l'Atlantique canadien. Les stocks ont été évalués d'après l'expérience d'autres pêcheries mieux établies et qui appliquent divers taux d'exploitation à des estimations d'effectif de stock obtenues par la méthode d'expansion d'aire. Une meilleure compréhension de la biologie des crevettes, plus particulièrement de la croissance, de la mortalité, du recrutement, des relations prédateurs-proies et des facteurs ambiants, contribuerait à améliorer la méthodologie actuellement utilisée.

Il n'y a pas beaucoup d'alternatives à l'évaluation des stocks de crevettes. Les modèles analytiques traditionnels de pêcheries peuvent être utiles, à condition que la précision des paramètres biologiques soit plus raffinée. Les récents progrès dans l'analyse des fréquences de longueurs pourraient s'appliquer aux données sur les crevettes.

La recherche devrait mettre l'accent surtout sur l'amélioration des méthodes existantes et le développement de méthodes nouvelles plutôt que sur l'évaluation annuelle de plusieurs stocks.

Introduction

During the annual assessment of the northern shrimp stocks in early 1982, the need for a more thorough review of shrimp management objectives, the methodology applied in the conduct of shrimp assessments and associated research was identified. To this end a workshop was held by CAFSAC in November of 1982. The following is a summary of methods used in the assessment of shirmp stocks in the Northwest Atlantic (1976 to present), associated assumptions, and areas where improvements are essential.

Historical Review

Shrimp stocks in the northwest Atlantic occur over a vast geographic range. Canadian fishermen have vested interest in concentrations found in Davis Strait, Hudson Strait, Labrador Sea, Gulf of St. Lawrence, and Scotian Shelf (Fig. 1). CAFSAC is concerned with the management of all these stocks, except for that found in the Davis Strait which is assessed by NAFO. However, since Canadian scientists actively participate in the NAFO meetings and influence and/or are influenced by the results of the assessments, this area will be considered as well.

In most cases the northern shrimp, *Pandalus borealis*, is the species under consideration except in the eastern Hudson Strait where the species is *P. montagui*. Whether or not these concentrations constitute separate stocks is another matter. At present, because concentrations are fairly easily defined both geographically and in terms of fishing patterns (ie., gear, vessel size, etc.), they tend to be treated as such. Studies on stock discrimination for shrimp in these areas are lacking primarily because most research effort has been centered around assessment of the easily-defined fisheries. It is generally assumed that shrimp concentrations in adjacent areas do not intermingle sufficiently to significantly affect 'regional' assessments.

Most of these fisheries are relatively new. In the Davis Strait, the offshore fishery began in the early 1970's with Canada actively participating only since 1979. No fishery for *P. montagui* has developed yet in the eastern Hudson Strait but there has been some exploratory fishing and two research surveys, one in 1979 and another in 1982. The directed shrimp fishery off Labrador began in 1977 (Sandeman 1978a). Foreign vessels have been chartered to fish the resource but there is an ongoing effort to 'Canadianize' the fleet. Shrimp fishing in the Gulf of St. Lawrence began in the mid 1960's in an area off Sept-Iles, Quebec (Fréchette 1982). In the early 1970's a fishery was developed on the west coast of Newfoundland at Port-au-Choix (Sandeman 1978b). Vessels from this area fished concentrations in the northern Esquiman Channel. Vessels from Quebec and New Brunswick also fished in an area north of Anticosti Island where significant landings have been recorded since 1974. In the late 1970's, landings of shrimp also have been reported from an area south of Anticosti Island and in the Gulf of St. Lawrence estuary (Fréchette 1982). Also in the late 1970's, a fishery began on the eastern Scotian Shelf where shrimp are concentrated in deep depressions. Canso, Misaine, and Louisbourg are the three areas presently being exploited (Labonté 1980).

In any review of assessment methodology it first must be recognized that for most shrimp fisheries the data series is relatively short. In some areas there has hardly been enough time for fishermen to attain optimum harvesting strategy (speaking for the fleets as a whole) or for the stocks themselves to show a response to the increased mortality. Yet we are continually challenged to employ sophisticated analytical models which thrive on good time series for their credibility. Although this workshop was designed to ameliorate stock assessment, the paucity of data cannot be ignored. Good time series has to be the foundation for good assessment methodology. In the meantime, proper guidelines need to be formulated to effectively manage the resource.

Davis Strait (Subareas 0+1)

Assessment of the offshore shrimp resource in this area was first conducted by ICNAF (STACRES) in 1976 after a Danish proposal in 1975 to regulate the fishery (ICNAF 1976). Stock size was estimated from commercial catch and effort data at 80-90,000 t for age groups recruited to the fishery. Although it was recognized areal expansion methods tend to underestimate stock size, some caution was expressed concerning extensive extrapolation of these data over a large area. Another analysis assumed that yields in the offshore area would be similar to those obtained in the Disko Bay which were themselves assumed to approximate the MSY level for this area. MSY for the offshore grounds was thus estimated at 26,000 t annually. Possible recruitment of shrimp in the Disko Bay from adjacent areas was considered in the analysis.

General biological considerations included the possible relationship between the high stock density of shrimp at that time and the low level of the cod stock - a predator/prey relationship. Other management problems included potential for localized overfishing and mesh size regulation. Effort regulation ± TAC (by division or specific fishing grounds) was offered as a solution to the former and it was agreed that the most proper mesh size for the codend was around 44 mm stretched mesh. Meshes of this size would diminish the catch of small shrimp (age-group 3) but would not reduce catches of larger shrimp to any great extent.

The Commission deferred the setting of TAC and allocations for 1977 to a later meeting in 1976 when new information became available. Several estimates of stock size were then presented for various areas. For example, the estimates for Division 1B ranged from 54,000 t to 184,000 t. Limitations of the swept area method were discussed from points of view of over and underestimating stock size. Data from research surveys tended to produce underestimates while extrapolation of commercial CPUE data over large areas could cause serious overestimation. A 'reasonable minimum estimate' of 100,000 t for the offshore component of the West Greenland shrimp stock in 1976 was eventually produced.

As an alternative to the theory of MSY, it was concluded that a safer position would be to maintain a spawning stock at roughly 50% of the virgin level. Ulltang (1978) presented a method for calculating how much the fishery reduces the spawning stock. Critical parameters are mortality after first spawning (M_1) and the time between recruitment to the fishery and first hatching (t). The latter can be reasonably estimated from existing biological data. M_1, however, is much more nebulous and the model is sensitive to large errors in its estimation. The value of M_1 was assumed to be 1.5 and t = 1.5. The resulting fishing mortality which would lead to a 50% reduction in spawning stock according to the model was 0.4 (Table 1). Assumming a fishable stock biomass of 100,000 t, a TAC of 40,000 t was recommended for 1977. It also was advised that, because yield in a given year is extremely dependent upon recruitment in that year, the situation should be re-evaluated at the beginning of each fishing season. Other advice included a recommendation that the minimum mesh size of 40 mm be adopted and that an area adjacent to Disko Bay be limited to 3,200 t annually to account for possible dependency of inshore grounds on offshore shrimp resources.

The same advice was given for 1978 since there was no indication that fishable biomass had changed appreciably between 1976 and 1977 (ICNAF 1978). However, by late 1978, a decrease in the order of 20-32% was interpreted from research survey (photographic and trawl) and commercial catch rate data. A similar reduction in TAC was advised (ICNAF 1979) and in 1979 the catch level was restricted to 29,500 t. Since 1978, abundance indices have suggested that the stock has remained relatively stable and advice for a TAC of 29,500 t has been reiterated (NAFO 1981).

The assumption that M_1 used in the Ulltang model was 1.5 apparently interpreted the last prominent mode in the length frequencies to represent one age group. Recent information suggests that the last prominent mode is actually composed of two modes, first time spawners and multiple spawners (eg. Fréchette and Parsons 1983). If more than one age group is present, M_1 may be much lower than 1.5.

Canadian Northwest Atlantic

Assessment of shrimp stocks in Canadian waters has a common foundation. Initial assessments were conducted in the late 1970's for stocks off Labrador. The methodology used for these areas was extended to include shrimp stocks in the Gulf of St. Lawrence and on the Scotian Shelf. In more recent years, effort has been focused on the standardization of techniques, ensuring on one hand that basic assumptions have been consistent between areas while, at the same time, recognizing inherent differences between the stocks and fisheries.

In early 1978, CAFSAC considered shrimp stock assessments in Subarea 2 (Sandeman 1978a). There were lengthy reviews on environmental issues (ie., shrimp living at the lower end of the temperature range), natural mortality and sources of error in the estimation of 'sustainable yield'. Sources of error were identified and elaborated for both areal expansion and fishing success methods used to estimate stock biomass. Problems were also identified with the theory of general production modelling (maximum production at 50% of the virgin biomass) and examples were quoted where certain fisheries had been managed at well below this level. These included the developing years of the California shrimp fishery (50% available biomass) and recent developments in the Sept-Iles fishery (40% available biomass). Some stability in yields was noted in the latter. Since females were more vulnerable to exploitation (ie., size), catch levels below those predicted by the approximation formula were preferred.

Accordingly, in assessing the quotas, a range of options was considered.

1. $Y = 0.5\ M\ B_0$ (M = 1.0). The validity was questioned due to uncertainty in regularity of recruitment and the value of M.

2. 50% reduction in spawning stock size as used by ICNAF/NAFO. Thus, values of F = 0.35, M = 1.0 were used in the catch equation

$$C = \frac{B_0 F}{Z}(1-e^{-Z})$$

rather than the apparent use of $Y = F\bar{B}$ by ICNAF. The estimates were considered conservative.

3. Maximize Y/R, accepting Icelandic shrimp stocks as a representative model (M = 0.35, F = 0.5). The catch equation was again employed.

4. 40% available (exploited) biomass interpreted as sustainable in the Sept-Iles fishery.

The four methods produced wide ranges of estimates from which recommended catch levels were compromised. Effort required to obtain these catches was also estimated by taking the geometric mean of declining (exponential) catch rates over the season. Recommendations for future management emphasized the need to determine whether or not the stocks were self-sustaining and to develop indices of pre and early recruit abundance.

Consideration of shrimp stocks in the Gulf of St. Lawrence was undertaken by CAFSAC in April 1978 (CAFSAC 1980a, Sandeman 1978b). Data from all areas were generally considered to be inadequate for use in analytical or general production modelling. It was felt that the approximation MSY ≃ 0.5 M Bo (M = 0.53) was most appropriate for estimating TAC's in the Sept-Iles and Esquiman Channel fisheries, both areas being subjected to moderate exploitation. The value of M was estimated from survey data for the Sept-Iles stock. This method was used in fact with estimates of Bo (virgin) for all areas at this time. A coefficient of catching efficiency of 0.75 was applied to all biomass estimates obtained using Yankee 36 trawls.

Additional advice was given on fleet size (Sept-Iles, South Anticosti) and partitioning of the TAC to prevent localized overfishing (Esquiman Channel). The economic assessment of fleet fishing the Esquiman Channel also was addressed in relation to possibilities for fleet expansion.

Later in 1978, an assessment was made of shrimp stocks on the eastern Scotian Shelf. Estimates of MSY were obtained again using the 0.5 M Bo approximation (M = 0.5 from Sept-Iles data) and a TAC around 2000 t (equivalent to roughly 1000 vessel-days) was recommended (CAFSAC 1980b).

The approximation formula was maintained as the basis for advice for Labrador shrimp stocks in 1979. A value of M = 0.7 was used based on new estimates of mortality of female shrimp in the Gulf of St. Lawrence.

Assessments in 1980 for Gulf stocks relied mainly on the Sept-Iles experience (CAFSAC 1982a). It was agreed that harvesting at 40% of the current fished down biomass was most applicable since the equation was based on empirical evidence and appeared to approximate the MSY. This relationship was estimated to be roughly equivalent to 25% Bo. Assessment of Labrador stocks maintained estimates of the previous year (approximation formula) but made adjustments to the TAC's based on trends in catch rate data (stability or instability) and new information on the horizontal opening of the Sputnik trawl (areal expansion). The same approach was used the following year and TAC's for 1981 were maintained at the 1980 levels due to relative stability in abundance indices. A marked increase in 1980 in the abundance of a shrimp predator, Greenland halibut, was observed and considered in the assessments. This potential for increased mortality contributed to the more conservative interpretation of the available data (status quo). It was further recommended that these predator-prey investigations should be expanded.

Shrimp (Pandalus montagui) stocks in eastern Hudson Strait and Ungava Bay were assessed for the first time in 1981 (Parsons et al. 1981). Since no biological parameters were available for these stocks, the Sept-Iles approximation was employed, in this case 25% of the virgin biomass. This percentage was applied to the mean biomass estimates for the Ungava Bay stock and to the 95% confidence intervals for estimates for the Hudson Strait stock, providing options for catch levels. However, because of the paucity of biological information it was recommended that removals in the order of 100 t for each area would be unlikely to cause a decline in the stocks (CAFSAC 1982b).

Shrimp assessments for the Scotian Shelf and Gulf of St. Lawrence in 1981 generally maintained MSY estimates of the previous year and provided advice on fleet size and management aimed at preventing localized overfishing (CAFSAC 1982c).

Some of the 1981 assessments generated questions concerning the use of MSY for shrimp stocks. It was generally conceded that since shrimp abundance can change dramatically over time, the concept of MSY as it normally applies, cannot be applied to shrimp stocks. Such estimates only should be taken as short-term projections and therefore, the 'Maximum Sustainable' part of the expression has no real application.

These concerns were reviewed early in 1982. It was determined that the expression MSY had often been used inconsistently, causing difficulty in the interpretation of CAFSAC advice. In fact, what had been used was a non-equilibrium yield estimate based on the empirical evidence from the Sept-Iles fishery. CAFSAC considered this reference point (an exploitation rate) acceptable for yield calculations. New information on trawl efficiency resulted in a revised estimate of 35% rather than 40% (CAFSAC 1982 Ad. Doc. 82/5, 82/6 and 82/7).

The 1982 shrimp assessments followed the guidelines given above. In 1982, mid season biomass estimates were used assuming catch and recruitment were reasonably balanced. Prior to 1982, the catch up to survey time was added to the biomass estimate. TAC's were recommended for all areas and the individual fisheries were assessed for potential expansion. Problems of localized overfishing were addressed for Esquiman Channel and the Scotian Shelf. Anomalous distribution patterns were observed in Hopedale Channel in 1981, affecting the interpretation of relatively low abundance indices. It was concluded that these indices did not reflect true stock abundance and the 1981 catch level (4000 t) was maintained in 1982.

Although the history of shrimp stock assessment is not associated with sophisticated modelling (for whatever reasons), there has been a systematic and conscientious approach which does not rely completely on rough estimates of stock size. A lack of theory has necessitated a more pragmatic approach which has considered amount and distribution of fishing effort, economic factors, localized overfishing, abundance of predators and seasonal/annual distribution patterns of the shrimp themselves. These areas of concern should not be abandoned in favour of more quantifiable methods, but developed further along with the latter.

Means of Improvement

In light of the situation presented above, improvement of assessments could follow two main routes. Presumably, priority must be placed on the development of alternate methods of assessment, preferably quantifiable and capable of making predictions. However, since this will not happen overnight, it is also necessary to improve on current methodology which can be used effectively in the meantime from a management point of view. By addressing the latter in this review, many of the problems associated with shrimp stock assessment should become clear, thereby laying a reasonably firm foundation for discussion of the former during this workshop.

Perhaps the most fundamental issue in shrimp stock assessment is the definition of the stock. Efforts should be initiated to determine where the lines should be drawn. There has been some suggestion that in certain areas the shrimp may belong to a single stock but fished in well-defined areas of concentration (eg., Gulf of St. Lawrence and the Labrador Channels). However, statistical analyses of weight/length and fecundity/length for shrimp in the Labrador Channels have shown differences between areas (Parsons 1982). These studies can be made fairly easily provided they are given some priority. The question is much more than academic, especially where recruitment mechanisms become important issues. Answering these questions adds perspective to management concerns such as localized overfishing.

It has been pointed out that these shrimp fisheries are new and the data scanty. In order to ensure that analytical models can be employed as quickly as possible, adequate sampling programs must be maintained. This includes commercial catch sampling and repetitive research surveys. For the development of new assessment methodology, it appears that the Sept-Iles fishery would provide the most extensive data series. The grounds are close to shore and readily accessible for ad hoc sampling.

Serious errors occur in the estimates and indices of fishable stock size. Variablity occurs on diel, seasonal, and annual bases and is not related entirely to changes in abundance. This places onus on the timing of the research surveys. Interpretation of CPUE faces the same problems since only times of similar availability should be examined to interpret changes in abundance. The traditional trawl surveys and photographic surveys generally produce estimates with wide confidence intervals, resulting from the diel variability problem. Although traditionally related to vertical migration of shrimp at night, recent work has suggested other environmental problems affecting the catchability of the gear (Parsons and Sandeman 1981) and/or availability of shrimp. Recent analysis of data on 24-hour fishing off Labrador shows that, in addition to light, speed and direction of bottom currents also account for some of the variabilty in the catch data. A recent survey in the Hudson Strait indicated that variance in catch data could be reduced up to approximately 15% by accounting for changes in distance towed due to changing surface currents (Fig. 2, Table 2). This demonstrates the need for accurate recordings of characterstics of each fishing set involving the use of bottom lock sounders.

Even if confidence intervals are ignored for the moment, survey estimates can vary due to seasonal and annual differences in availability. Survey results off Labrador in 1978 and 1981 were interpreted to reflect changes in distribution, hence availability, rather than changes in abundance (Parsons et al. 1979, 1982).

Faced with a seemingly insurmountable variability problem, it appears that the only solution for producing acceptable results is strict standardization including multivariate-type analyses of factors affecting shrimp catches.

Natural mortality (M) has been interpreted over a wide range, 0.25-1.50, for shrimp stock assessment purposes. Recent work in the Gulf of St. Lawrence has resulted in more 'moderate' values (0.5-0.8) for fully-recruited animals (Labonté 1980; Fréchette and Labonté 1981, Fréchette and Parsons 1981). However, most models are sensitive even to small changes in M. The conventional methods for estimating M are often difficult to employ due to changes in availability, rather than abundance. General approximations provide, at least, a starting point and should be considered initially (eg., $M \simeq 1/T$ (mean life expectancy), Pauly 1980, etc.).

Problems of ageing further complicates estimation of mortality for northern shrimp. Assessment of penaeid shrimp stocks encounters similar problems (Garcia and LeReste 1981). NAFO recently held a shrimp ageing workshop to discuss the situation. Much of the workshop focused on length frequency analysis and the methods available for breakdown of components in a polymodal distribution. However, most important was the biological interpretation of the modes themselves and it was in this area where information was lacking. Defining the age structure of shrimp stocks should be given high priority, following recommendations provided in the report of the shrimp ageing workshop.

Since northern shrimp fisheries are directed at the larger animals (females), the 'sustainability' is heavily dependent on recruitment between fishing seasons. To date, little success has been achieved in modelling stock/recruitment relationships. Part of the problem is the lack of a reliable recruitment index. Research trawl surveys (using small mesh liners) seldom capture significant amounts of very small shrimp, even though surveys are usually stratified by depth. One approach would be to initiate studies on the distribution of larvae which eventually could be related to stock abundance indices some time hence. Provided availability of age groups is somewhat consistent between years, some indication of relative year-class strength might be obtainable through modal analysis of research survey data (eg. Fréchette and and Parsons 1981).

It appears that cod, important shrimp predators, are relatively indiscriminate when it comes to choosing the size of the prey. Length frequencies of shrimp found in cod stomachs taken off Labrador show an additional mode of very small shrimp which is not obvious in the trawl catches (Fig. 3). A careful analysis of this type of data between years might give some indication of future recruitment at least one year earlier than could be interpreted from trawl survey data. The added information should also help in age and growth studies.

Also, because of the importance of recruitment to yield in a given year, the recommendation of re-evaluation of stock status at the beginning of each fishing season (ICNAF 1977) should be considered. This check system may not necessitate formal annual meetings but would require periodic review of abundance and recruitment indices.

It was previously mentioned that ICNAF, in its early assessment of Davis Strait stock, noted a low abundance of cod at a time when shrimp abundance was high. There now appears to be some concern that the cod stock in that area may be increasing and may have affects on the shrimp resource. Unfortunately, there are no data to further investigate this possible predator-prey relationship. Bowering and Parsons (1981) observed a significant increase in Greenland halibut in two Labrador Channels in 1980 and expressed concern for increased shrimp mortality. Predator abundance declined subsequently and damage appears minimal. Fréchette (1982) noted some relationship between decline in Greenland halibut catch rates and increasing shrimp catch rates in the Sept-Iles area. Bowering et al. (1982) noted that cod off Labrador fed heavily on shrimp and that although less abundant than Greenland halibut, might consume more shrimp per unit biomass.

In relation to the latter, it is worth noting that the shrimp stock in the Cartwright Channel has not been fished heavily since 1979. Yet abundance indices have not indicated any response to the virtual elimination of fishing mortality (eg., the 1982 biomass estimate is slightly lower than the 1981 estimate). Catch per hour of tonnage class 5 stern trawlers participating in the winter-spring cod fishery in and near the Cartwright Channel has increased since 1978, quite noticeably in 1981 and 1982 (S. Gavaris, pers. comm.). A similar increase in cod biomass is indicated in results of July research surveys for shrimp.

Shrimp are obviously tempting morsels to a number of fish species. Any changes in abundance of the latter in areas where shrimp abound should be thoroughly investigated.

Responses of shrimp to changes in water temperature has continually been a concern in stock assessment. In northern areas, they are found at the lower end of the range of temperature tolerance (~ 3°C). In southern areas such as the Gulf of Maine and southwest Nova Scotia, they live in much warmer waters. Declines of shrimp stocks in both these southern areas have been related partly (circumstantially) to increased bottom temperatures. Research surveys should continually monitor bottom temperatures and other potential indicators of environmental change should be periodically observed (eg., fecundity, growth).

Conclusions

Assessment of shrimp stocks in the northwest Atlantic has been based, primarily, on empirical considerations. This is an acceptable approach for developing fisheries (Hancock 1979) while the data base for more sophisticated models increases. During these developmental years, some inconsistencies in advice can be expected as we learn how the stocks will (or will not) react to increased mortality and/or how the fleets attain optimal harvesting efficiency (eg., gear type, vessel size, distribution of effort).

Problems of changing availability and difficulties encountered in ageing shrimp complicate the assessment procedure. These factors should be considered in the development of alternate assessment methods. The sensitivity of shrimp stocks to their environment (ie., predators and temperature tolerance) also should be included in the equation.

Assuming that alternative methodology may be developed in response to this workshop and that a longer time series is necessary before most stocks can be assessed by more complex models, it might seem reasonable to provide advice on the approaches to assessment in the meantime. Exploitation rates based on empirical observations from other fisheries provide a good reference point only if such rates are applied to estimates of biomass which are subject to the same biases. It matters little whether the estimates are absolute or merely indices of abundance since the Sept-Iles 'model' as presented appears to exhibit some kind of stability in yield. However, it is quite possible that biomass estimates for stocks in the Gulf of St. Lawrence, for example, may more accurately represent stock size than those from Labrador, problems of variability being greater in the latter. The 35% exploitable rate derived from the Sept-Iles experience loses credibility under such circumstances. In areas where variability in survey data is high, it may be more effective to impose a higher rate, recognizing that the hypothetical ratio of estimated stock size to actual stock size will be lower than in the Sept-Iles area.

Once average productivity has been established, more time can be spent researching existing problems rather than performing annual assessments of numerous stocks. Formal meetings for reassessment could be held every three years, perhaps. However, an ongoing system of checks should be examined annually including research survey results and comparative performance of the fleet. Development of new assessment methodology can be reviewed critically and tested when they become available, either at regularly scheduled CAFSAC meetings or specialized workshops.

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TABLE 1. Ratio of spawning (hatching) stock size (numbers) to virgin spawning (hatching) stock size (S/S_0) for various values of fishing mortality (F), natural mortality after first spawning (hatching) (M_1), and time (t) between recruitment to the fishery and first spawning (hatching).

	t = 1.0			t = 1.5			t = 2.0		
F	M_1 =0.75	M_1 =1.00	M_1 =1.50	M_1 =0.75	M_1 =1.00	M_1 =1.50	M_1 =0.75	M_1 =1.00	M_1 =1.50
0.1	0.834	0.857	0.881	0.793	0.816	0.838	0.754	0.776	0.797
0.2	0.704	0.741	0.778	0.637	0.670	0.704	0.577	0.606	0.637
0.3	0.601	0.644	0.689	0.518	0.554	0.593	0.445	0.477	0.511
0.4	0.518	0.562	0.612	0.424	0.460	0.501	0.347	0.377	0.410
0.5	0.449	0.494	0.545	0.349	0.384	0.424	0.272	0.299	0.331
0.6	0.391	0.435	0.486	0.290	0.322	0.360	0.215	0.239	0.267
0.7	0.342	0.384	0.434	0.241	0.271	0.306	0.170	0.191	0.215
0.8	0.301	0.340	0.388	0.202	0.228	0.260	0.135	0.153	0.174
0.9	0.266	0.302	0.347	0.169	0.193	0.221	0.108	0.123	0.141
1.0	0.235	0.269	0.311	0.142	0.163	0.189	0.086	0.099	0.115
1.2	0.185	0.214	0.251	0.102	0.118	0.138	0.056	0.064	0.076

From Ulltang, 1978

Table 2. Adjustment of diel catch data to standard tow of 1.5 nautical miles.

Set No.	Distance towed (n. miles)	Catch (kg)	Adjusted catch (kg)	% Difference
51	1.57	302	289	4
52	1.62	250	231	8
53	1.55	406	393	3
54	1.80	726	605	20
55	2.20	347	237	46
56	2.24	291	195	49
57	2.03	136	100	36
58	1.85	293	238	23
59	1.64	583	533	9
60	1.54	467	455	3
61	1.50	696	696	-
62	1.80	592	493	20
63	1.79	793	666	19
64	1.50	233	233	-

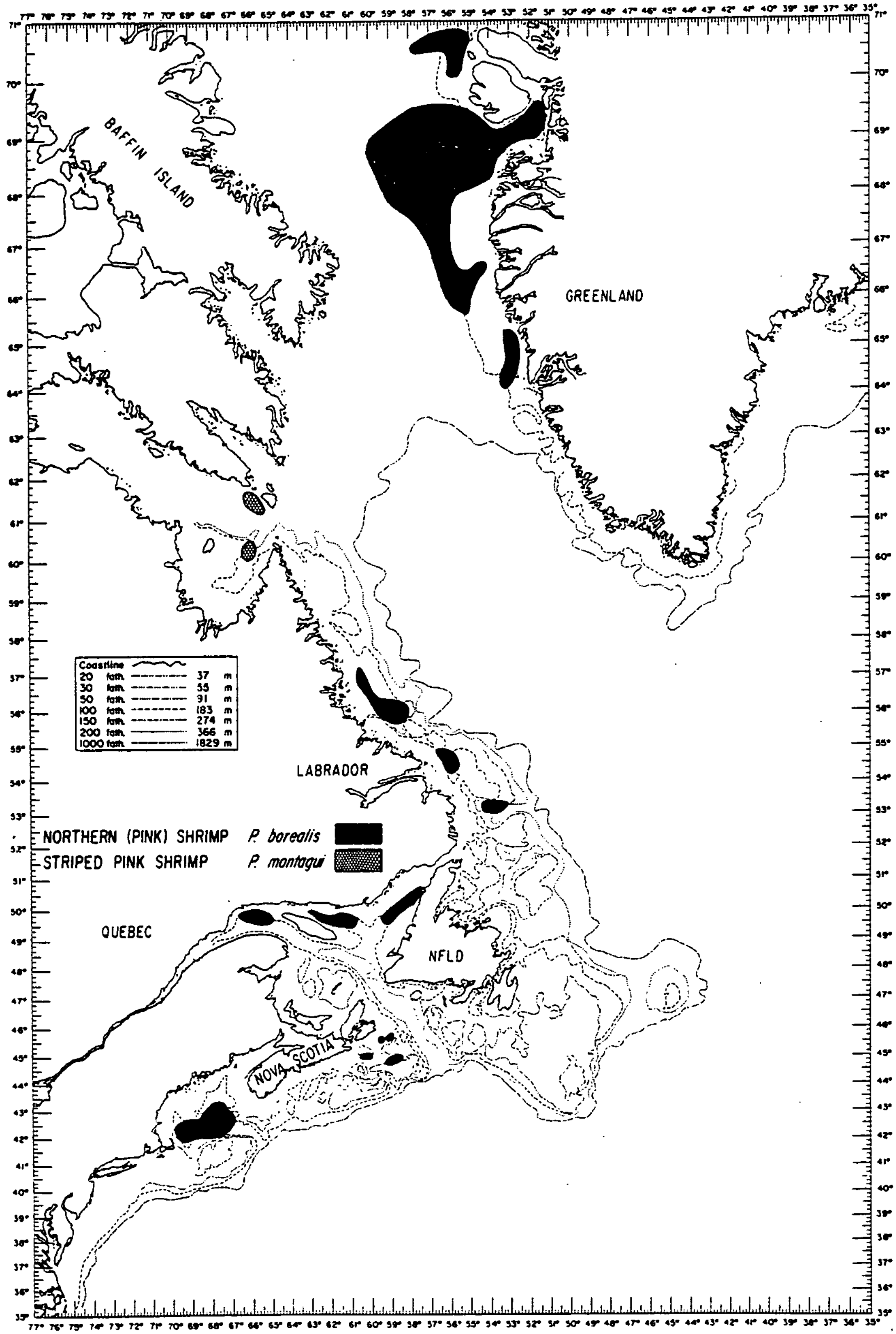

Fig.1. Pandalid shrimp fishing areas in the Northwest Atlantic.

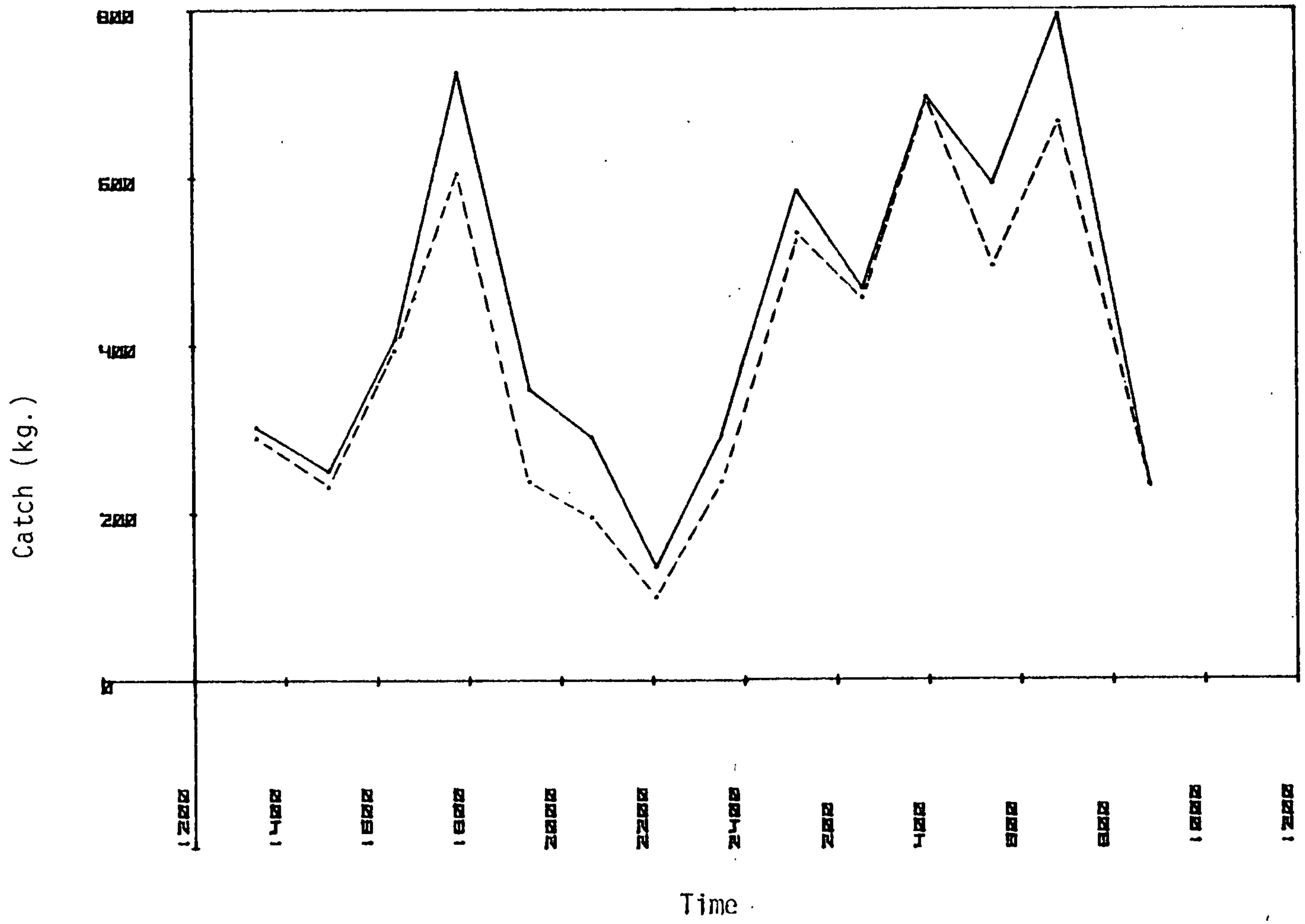

Fig.2. Shrimp catches from diel study - Eastern Hudson Strait, 1982.
(actual catch - solid line, catch adjusted to standard tow of
1.5 nautical miles - broken line)

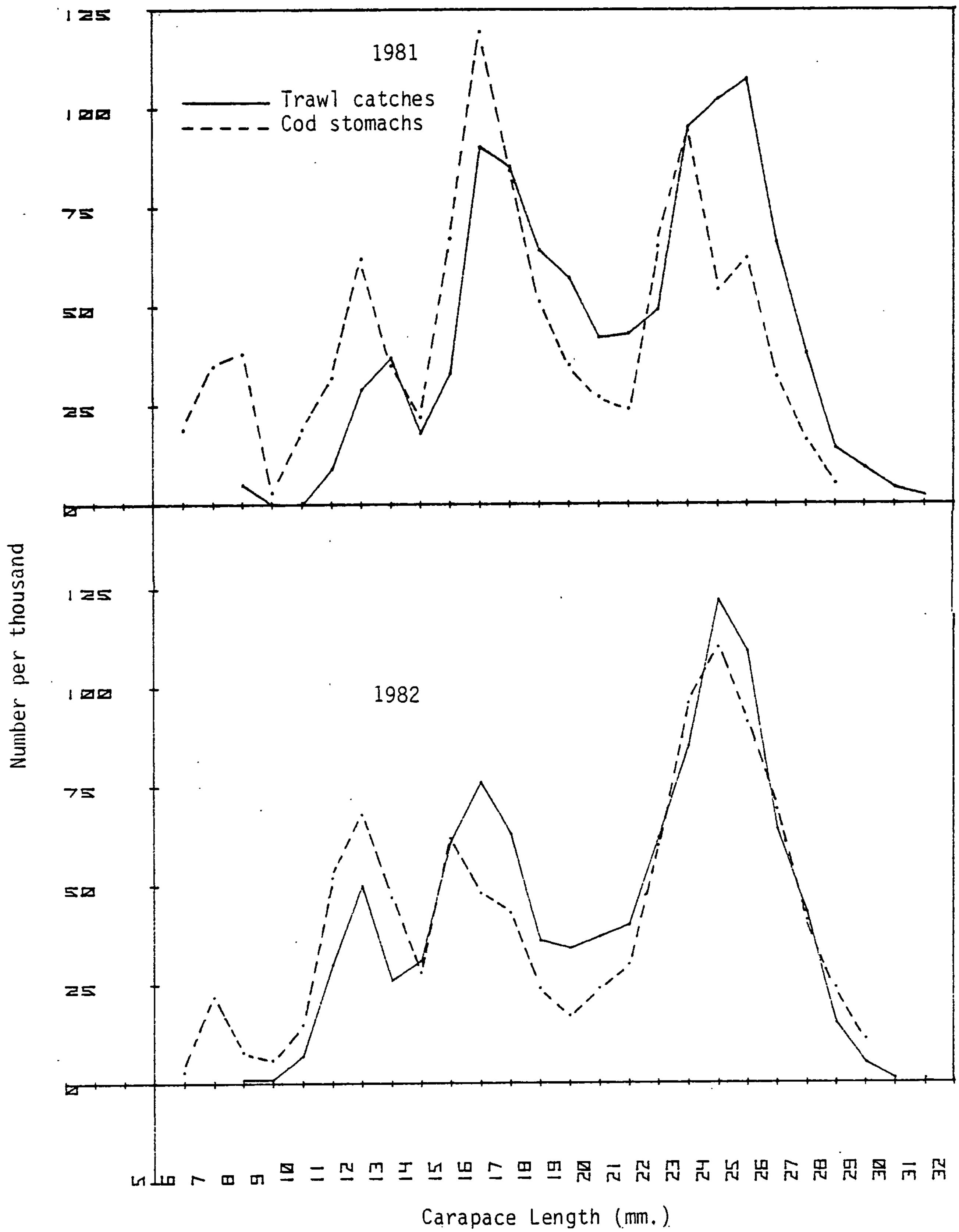

Fig.3. Length frequency distribution of shrimp from cod stomachs - Cartwright Channel, 1981 and 1982.